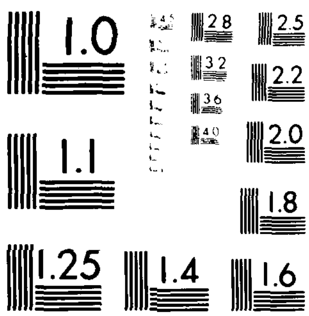
AD-A096 769 PENNSYLVANIA STATE UNIV UNIVERSITY PARK APPLIED RESE--ETC F/G 20/4
THE USE OF DISTRIBUTED ROUGHNESS FOR SCALING CAVITATION INCEPTI--ETC(U)
AUG 80 M L BILLET, J W HOLL N00024-79-C-6043
UNCLASSIFIED ARL/PSU/TM-80-177 NL

END
DATE
FILMED
4 81
DTIC



MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS-1963-A

LEVEL

(12)

AD A096769

THE USE OF DISTRIBUTED ROUGHNESS FOR
SCALING CAVITATION INCEPTION

M. L. BILLET and J. W. HOLL

Technical Memorandum
File No. 80-177
21 August 1980
Contract No. N00024-79-C-6043

Copy No. 7

The Pennsylvania State University
APPLIED RESEARCH LABORATORY
Post Office Box 30
State College, PA 16801

NAVY DEPARTMENT

NAVAL SEA SYSTEMS COMMAND

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: TM 80-177
2. GOVT ACCESSION NO.: AD-A096
3. RECIPIENT'S CATALOG NUMBER: 769
4. TITLE (and Subtitle): (6) THE USE OF DISTRIBUTED ROUGHNESS FOR SCALING CAVITATION INCEPTION (9)
5. TYPE OF REPORT & PERIOD COVERED: Technical ~~Memorandum~~ memo.
6. PERFORMING ORG. REPORT NUMBER:
7. AUTHOR(s): (10) M. L. Billet ~~and~~ J. W. Holl
8. CONTRACT OR GRANT NUMBER(s): (15) N00024-79-C-6043
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Applied Research Laboratory, Post Office Box 30, State College, PA 16801
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS:
11. CONTROLLING OFFICE NAME AND ADDRESS: Naval Sea Systems Command, Washington, DC 20362, Code NSEA 63R-31 (11)
12. REPORT DATE: 21 Aug[redacted]80
13. NUMBER OF PAGES: 19 (12) 24
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): (14) ARL/PSU/TM-80-177
15. SECURITY CLASS. (of this report): UNCLASSIFIED
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release. Distribution Unlimited
Per NAVSEA - April 14, 1981.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

cavitation, inception, scaling, water tunnel, roughness

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Cavitation inception observations on a family of axisymmetric models were made in the 1.21 m water tunnel at the Applied Research Laboratory. Inception data were obtained on Schiebe headforms having diameters of 203.2 mm, 50.8 mm and 25.4 mm. The Schiebe headform has a $C_{p_{min}}$ = -0.75 and does not experience a separated boundary layer. Initially, cavitation inception data were obtained with no added roughness on the models. Then a distributed roughness of silicon carbide was glued to the nose of the two smaller models and additional cavita-

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

391007

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. tion inception data were obtained. Travelling-bubble cavitation was the type of cavitation observed near inception. Results show that it is possible to use a distributed roughness to increase the cavitation inception index to the indices found at higher Reynolds numbers. However the size and location of the roughness are very critical and the basic mechanisms which control this process need further investigation. This paper was presented at the 19th American Towing Tank Conference held in Ann Arbor, Michigan in July 1980.

Accession For	
NTIS GRA&I	☑
DTIC TAB	☐
Unannounced	☐
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A	

Subject: The Use of Distributed Roughness for Scaling Cavitation Inception

References: See page 12.

Abstract: Cavitation inception observations on a family of axisymmetric models were made in the 1.21 m water tunnel at the Applied Research Laboratory. Inception data were obtained on Schiebe headforms having diameters of 203.2 mm, 50.8 mm and 25.4 mm. The Schiebe headform has a $C_{P_{min}} = -0.75$ and does not experience a separated boundary layer. Initially, cavitation inception data were obtained with no added roughness on the models. Then a distributed roughness of silicon carbide was glued to the nose of the two smaller models and additional cavitation inception data were obtained. Travelling-bubble cavitation was the type of cavitation observed near inception. Results show that it is possible to use a distributed roughness to increase the cavitation inception index to the indices found at higher Reynolds numbers. However the size and location of the roughness are very critical and the basic mechanisms which control this process need further investigation.
This paper was presented at the 19th American Towing Tank Conference held in Ann Arbor, Michigan in July 1980.

Acknowledgments: This work was sponsored by the Naval Sea Systems Command, Code 63R-31.

TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

The practical problem of major concern in the field of cavitation is the prediction of cavitation inception for a prototype from model tests. The classical theory for scaling vaporous cavitation states that

$$\sigma_i = - C_{p_{min}} , \quad (1)$$

$$C_{p_{min}} = \text{constant} \quad (2)$$

and therefore

$$\sigma_{i-p} = \sigma_{i-m}$$

where σ_i and $C_{p_{min}}$ are the incipient cavitation number and minimum pressure coefficient, respectively. The subscripts p and m denote prototype and model. It is assumed that when scaling from one flow state to another the form of the flow field and its boundaries remain geometrically and kinematically similar and bubble dynamic effects are neglected.

Much of the experimental evidence on scaling [see References 1 and 2 for examples] shows that the incipient cavitation number is not a constant for a particular type of cavitation. In addition there appears to be a different scaling relationship for each type of cavitation, i.e. tip vortex, surface, travelling-bubble, etc. Even at model scale, differences in cavitation inception for a model occur between facilities [3].

There have been several recent results which explain more clearly why some of the departures occur. The importance of viscous effects, namely boundary layer transition and laminar separation, and free-stream nuclei have been pointed out by the extensive work of Arakeri and Acosta [4] and Gates [5]. These factors which cause departures from the classical theory are called "scale effects."

Because of these scale effects, some investigations have attempted to create "high Reynolds number simulations" at model scale in an attempt to eliminate the scale effects problem. A recent method used at NSMB [6]

is to coat the leading edges of model propellers with sand grain roughness The purpose of this method is to eliminate laminar separation which occurs at model scale but not at prototype scale. Some results do give cavitation patterns at model scale which approximate prototype patterns.

Another method is to seed the flow facility with cavitation nuclei to eliminate the scale effects problem. There are several investigators such as Albrecht and Bjorheden [7] and Kodama et.al. [8] who use this approach; however, the available results are not conclusive.

The objective of this paper is to present some of the results of a preliminary investigation into the influence of sand grain roughness on cavitation inception and "high Reynolds number simulations." Axisymmetric models with a Schiebe headform ($C_{p_{min}} = -0.75$) having diameters of 203.2 mm, 50.8 mm, and 25.4 mm were tested with and without added roughness. The contour of this headform is generated by a combination of a disk shaped source distribution normal to a uniform flow [9]. Van der Meulen [10] has investigated the flow around this headform and has verified that the body does not experience laminar separation.

EXPERIMENTAL PROGRAM

The experiments were conducted in the 1.21 m water tunnel of the Applied Research Laboratory located at The Pennsylvania State University. Both incipient and desinent cavitation data were obtained for the three Schiebe nosed models having diameters of 203.4 mm, 50.8 mm and 25.4 mm. These data were obtained by the following method: 1. the tunnel pressure was lowered until cavitation inception occurred, 2. the pressure was again lowered until developed cavitation appeared, 3. the pressure was increased until developed cavitation disappeared, and finally, 4. the

pressure was again increased until all cavitation disappeared. Thus, for most of the tests, this procedure yielded cavitation inception for travelling-bubble cavitation, cavitation inception for attached cavitation, cavitation desinence for attached cavitation and cavitation desinence for travelling-bubble cavitation. In addition to the cavitation data many photographs of the cavitation were also obtained.

Initially, cavitation data were obtained with no added roughness on the models. Then, a distributed roughness of silicon carbide in a size range of 15 to 66 microns was glued to the nose of the models. The roughness was applied to the nose in circular areas of different radii around the stagnation point. A photograph of the roughness on the 50.8 mm diameter model is shown in Figure 1.

EXPERIMENTAL RESULTS

Cavitation Characteristic Without Added Roughness

Cavitation inception data for the three models are shown in Figure 2 as a function of Reynolds number. In this figure the data points are an average of four tests and the bars indicate the amount of scatter in the data.

Cavitation inception always occurred near the body surface and slightly downstream of the $C_{p_{min}}$ point. Travelling-bubble events occurred very randomly. Inception of the attached cavity was marked by the sudden appearance of a steady developed cavity.

Both inception and desinent data are shown in Figure 3 for the 203.2 mm and 50.8 mm models. A brief analysis of inception data shows that in most cases average desinent data are higher than the corresponding

inception data. However this difference is within the data scatter for most cases. Thus, there was not a significant hysteresis effect in these experiments.

Referring to Figure 2 it is seen that there is a significant scale effect for the bodies both for travelling-bubble cavitation and for attached cavitation. On the average, σ_i for travelling-bubble cavitation decreased slightly with increasing velocity for all bodies and increased with model diameter. The incipient cavitation number for attached cavitation increased with increasing velocity for all models. For an increase in diameter from 25.4 mm to 50.8 mm, σ_i for the attached cavitation was essentially constant for a given velocity. However, σ_i increased significantly when the diameter was increased from 50.8 mm to 203.2 mm. However, as reported in Billet and Holl [2] for travelling-bubble cavitation on NACA 0010 hydrofoils, the velocity scale effect was the same as that observed for travelling-bubble cavitation on the Schiebe headforms whereas there was no size effect.

As discussed in the introduction, free stream nuclei can be important in cavitation scaling. A crude method of reducing the number of free stream nuclei is to de-gas the water. This was done for one set of tests with the 203.2 mm model. Inception data are shown in Figure 4 for an air content of 7.1 ppm and 3.2 ppm*. Reducing the gas content from 7.1 ppm to 3.2 ppm caused a reduction in σ_i over the entire velocity range for both travelling-bubble cavitation and attached cavitation. However, the amount of reduction in σ_i for the travelling-bubble cavitation was considerably greater than that for the attached cavities.

---

*Air contents are expressed in moles of air per million moles of water (ppm).

Cavitation Data With Added Roughness on the 25.4 mm and 50.8 mm Models

Incipient and desinent cavitation data were obtained with a distributed roughness added to the nose of the models. Roughness was added to the 25.4 mm and 50.8 mm diameter models upstream of the $C_{p_{min}}$ position. Two sizes of roughness were used having mean diameters of 30 μm and 66 μm. In all cases, silicon carbide grit was glued to the nose to form a disk area of radius R of distributed roughness.

Many tests were conducted in which the normalized radius (R/R_m) of distributed roughness was varied from 0.5 to 0.7 where R_m denotes model radius. In some cases the cavitation was observed to be attached to the roughness which caused a large change in cavitation index and in other cases no change in cavitation index was observed.

There are many conclusions that can be made from the tests with added roughness. Some of these are very noteworthy and these data will be presented and discussed.

First of all an additional type of cavitation called fixed-patch cavitation was observed. This is simply a patch of cavitation attached to the surface near the $C_{p_{min}}$ point on the body. In most of the cases this patch is downstream of the $C_{p_{min}}$ point and does not appear to be attached to roughness elements. Holl and Carroll [11] have previously discussed fixed-patch cavitation which was observed on axisymmetric headforms.

The 60 μm grit at $R/R_m = 0.5$ had no influence on bubble or attached cavitation for either body when compared to the cavitation data without added roughness. Using 30 μm grit at $R/R_m = 0.7$ gave the most interesting results. These data are shown in Figure 5.

On the average, the incipient cavitation number for travelling-bubble cavitation for the 25.4 mm and 50.8 mm noses with added roughness was higher than similar data for both bodies without added roughness. Also, the fixed patch cavitation for both bodies occurred at higher values of σ_i than did the attached cavitation for the bodies without added roughness.

DISCUSSION

The previous comments have been written with respect to the documentation of the experimental results. Let us discuss these results with emphasis on scaling.

Describing a possible scaling relationship with model size for the data shown in Figure 2 is difficult. Attached cavity cavitation varied significantly with model size but no correlation is obvious. However, σ_i for travelling-bubble cavitation was always greater than that for attached cavities and on the average increased with increasing size.

Considerable effort has been made in the past to formulate a dimensionless parameter or parameters which would scale travelling-bubble cavitation. Schiebe [12] has developed a reasonable approach for scaling using a parameter which involves the number of cavitation events per unit time normalized by the free stream velocity, the model diameter squared and the number of nuclei per unit volume. As discussed by Gates and Acosta [13], this approach does give a decrease in inception index for decreasing model size for Schiebe bodies. This decrease is essentially caused by a reduction in capture area as the model size decreases.

Now, let us address the question: What can roughness do to this process to make the scaling independent of model size? Another question which parallels the above is: Can roughness make cavitation inception independent of model size?

A comparison between cavitation inception data for the 203.2 mm model and the roughened 50.8 mm model is shown in Figure 6. It is seen that the average of the travelling-bubble inception data is similar between the 203.2 mm model and the 50.8 mm model with added roughness. In this case the roughness was not observed to cavitate directly. Thus the roughness formulation developed by Holl [14] and summarized in Arndt et.al. [15] cannot be directly applied.

A possible mechanism is found by referring to the previous discussion of scaling travelling-bubble cavitation. The roughness could generate micro-bubbles which would change the nuclei distribution for the model and thus offset the problem of reduced capture area at model scale. If this is possible, the location and size of the roughness is very critical. In addition, the micro-bubble generation for the roughness would be very sensitive to boundary layer conditions and hence would not be very useful over a large velocity range for the model. In addition, different roughnesses would be required for different scales.

SUMMARY AND CONCLUSIONS

The main objective of this paper is to present some experimental results of a preliminary investigation of the influence of sand grain roughness on cavitation scaling. To do this, a nonseparating test model was chosen which exhibits mostly travelling-bubble cavitation at inception. Three models having diameters of 25.4 mm, 50.8 mm, and 203.2 mm were tested. Roughness was added to the 50.8 mm "model" in an effort to obtain cavitation inception numbers typical of the 203.2 mm "prototype" without added roughness.

The results show that it is possible to use a distributed roughness to increase the cavitation inception index on the "model" to the level experienced by the "prototype" at higher Reynolds numbers. However, there are basic problems associated with this method:

(1) We cannot necessarily duplicate the same type of cavitation from model to prototype. In these experiments, the travelling-bubble cavitation was essentially the same but the attached cavitation was in the form of a patch on the model and was a developed cavity on the prototype.

(2) There does not appear to be a rational way to select the "proper" roughness since the cavitation occurs downstream from the roughness which suggests that the techniques of Arndt, Holl, Bohn, and Bechtel [15] are not applicable.

(3) We can match σ_i of the model and prototype by employing a trial and error process of adding roughness but to do this we must know σ_i of the prototype.

The mechanism by which the roughness indirectly increases the cavitation index for inception is not fully understood; however, it is suspected that the roughness produces micro-bubbles. The mechanics by which fixed patch cavitation is produced downstream of the roughness is also not understood; however, the roughness must change the structure of the boundary layer. This is only a preliminary investigation into the use of roughness. There are many questions which must be answered before roughness induced cavitation is understood.

REFERENCES

1. J. W. Holl and G. F. Wislicenus, "Scale Effects on Cavitation," Journal of Basic Engineering, Trans. ASME, Series D, Vol. 83, September 1961.

2. M. L. Billet and J. W. Holl, "Scale Effects on Various Types of Limited Cavitation," Proceedings of the International Symposium on Cavitation Inception, ASME, New York, New York, December 1979, pp. 11-24.

3. A. J. Acosta and H. Hamaguchi, "Cavitation Inception on the ITTC Standard Headform," Report No. E-149.1, Hydrodynamics Laboratory, California Institute of Technology, March 1967.

4. V. H. Arakeri and A. J. Acosta, "Viscous Effects in the Inception of Cavitation on Axisymmetric Bodies," Journal of Fluids Engineering, Trans. ASME, Vol. 95, Series 1, No. 4, December 1973, pp. 519-528.

5. E. M. Gates, "The Influence of Free Stream Turbulence, Free Stream Nuclei Populations and a Drag-Reducing Polymer on Cavitation Inception on Two Axisymmetric Bodies," Ph.D. Thesis, California Institute of Technology, April 1977.

6. G. Kuiper, "Some Experiments with Distinguished Types of Cavitation on Ship Propellers," Proceedings of the International Symposium on Cavitation Inception, ASME, New York, New York, December 1979, pp. 171-205.

7. K. Albrecht and O. Bjorheden, "Cavitation Testing of Propellers in a Free Surface Tunnel Utilizing Micro Air Bubble Control," Proceedings of Cavity Flows Symposium, ASME, Minneapolis, Minnesota, May 1975, pp. 1-10.

8. Y. Kodama, S. Tamiya, N. Take, and H. Kato, "The Effect of Nuclei on the Inception of Bubbles and Sheet Cavitation on Axisymmetric Bodies," Proceedings of the International Symposium on Cavitation Inception, ASME, New York, New York, December 1979, pp. 75-86.

9. F. R. Schiebe, "Measurement of the Cavitation Susceptibility of Water Using Standard Bodies," Report No. 118, St. Anthony Falls Hydraulic Laboratory, University of Minnesota, February 1972.

10. J. H. J. Van der Meulen, "A Holographic Study of Cavitation on Axisymmetric Bodies and the Influence of Polymer Additives," Publication No. 509, Netherlands Ship Model Basin, Wageningen, The Netherlands, 1976.

11. J. W. Holl and J. A. Carroll, "Observations of the Various Types of Limited Cavitation on Axisymmetric Bodies," Proceedings of the International Symposium on Cavitation Inception, ASME, New York, New York, December 1979, pp 87-100.

12. F. R. Schiebe, "Cavitation Occurrence Counting - a New Technique in Inception Research," Cavitation Forum, ASME, 1966, pp 8-9.

13. E. M. Gates and M. L. Billet, "Cavitation Nuclei and Inception," Proceedings of 10th Symposium of the IAHR, Tokyo, Japan, October 1980.

14. J. W. Holl, "The Inception of Cavitation on Isolated Surface Irregularities," Trans, ASME, Journal of Basic Engineering, Vol. 82, 1960, pp. 169-183.

15. R. E. A. Arndt, J. W. Holl, J. C. Bohn and W. T. Bechtel, "The Influence of Surface Irregularities on Cavitation Performance," SNAME, Journal of Ship Research, Vol. 23, No. 3, September 1979, pp. 157-170.

Figure 1. Photograph of Models

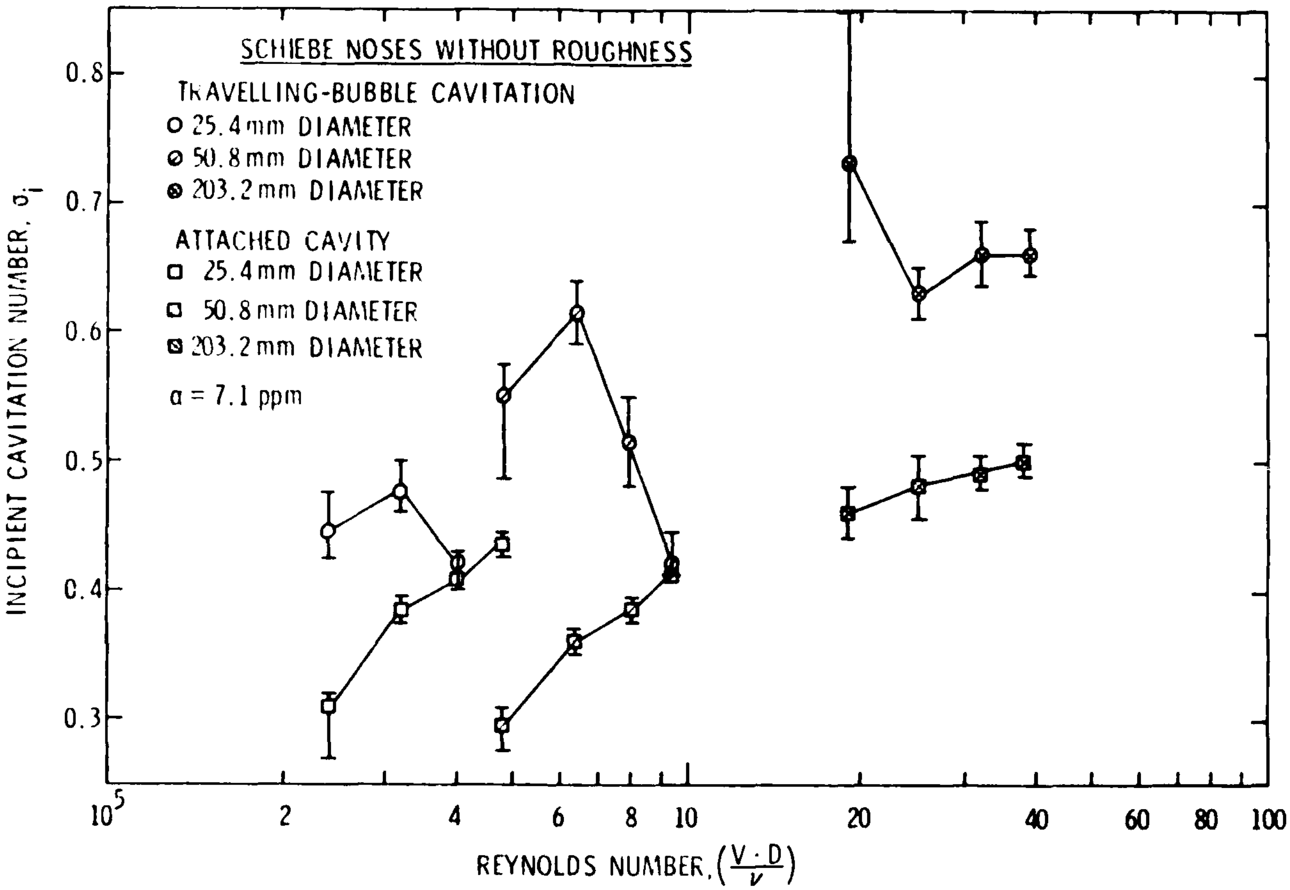


Figure 2. Cavitation Inception for Three Models

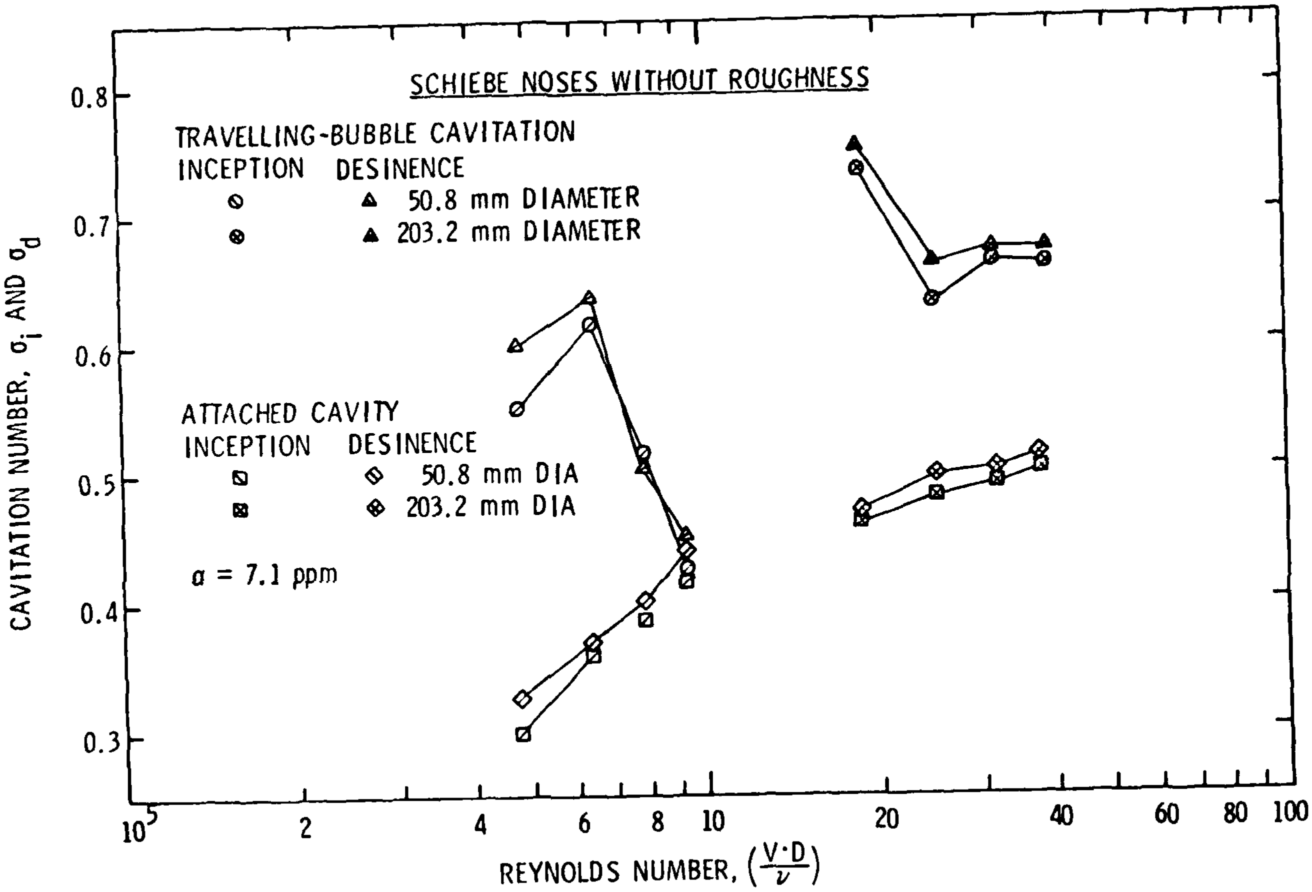


Figure 3. Comparison of Inception and Desinence for the 203.2 mm and 50.8 mm Models

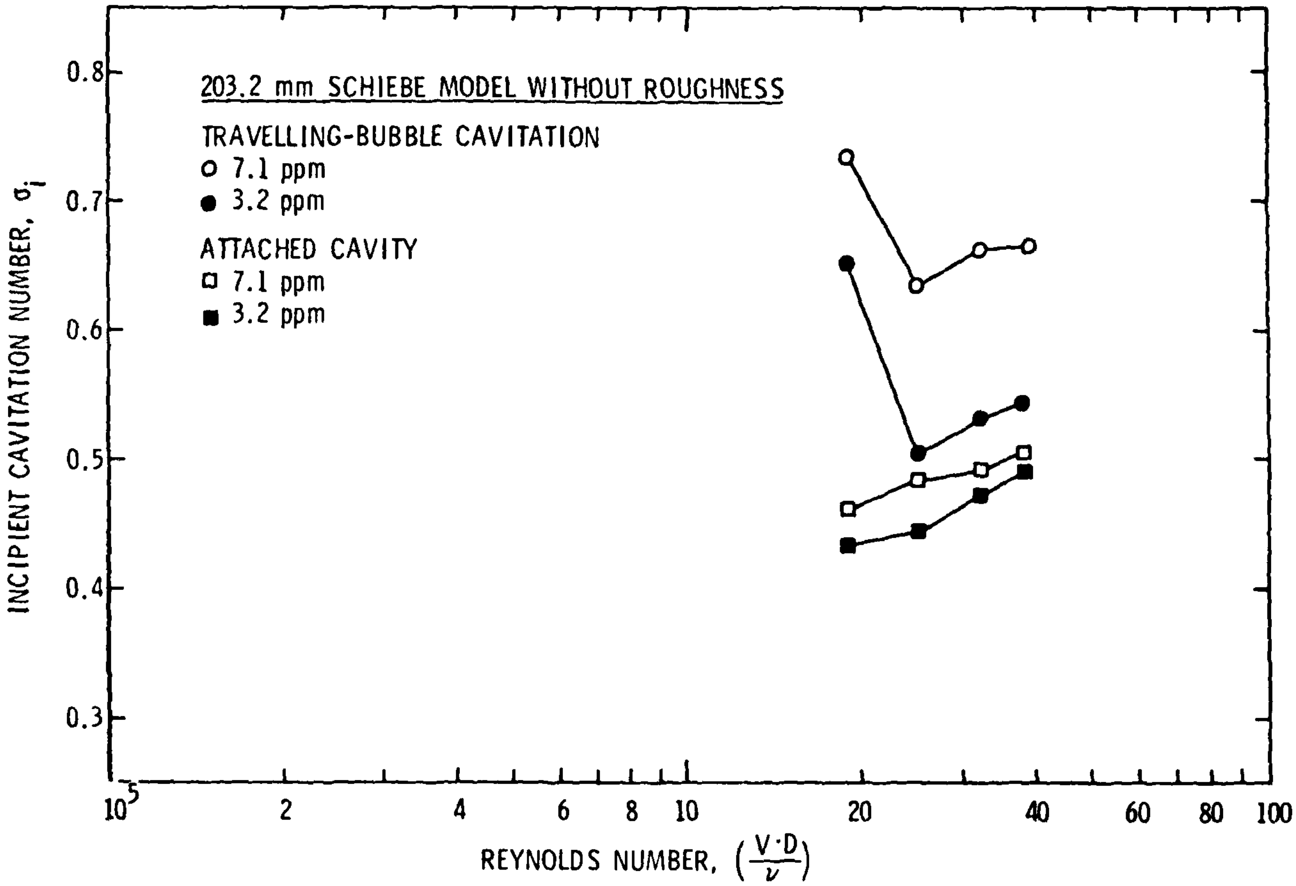


Figure 4. The Influence of Air Content on Inception for the 203.2 Model

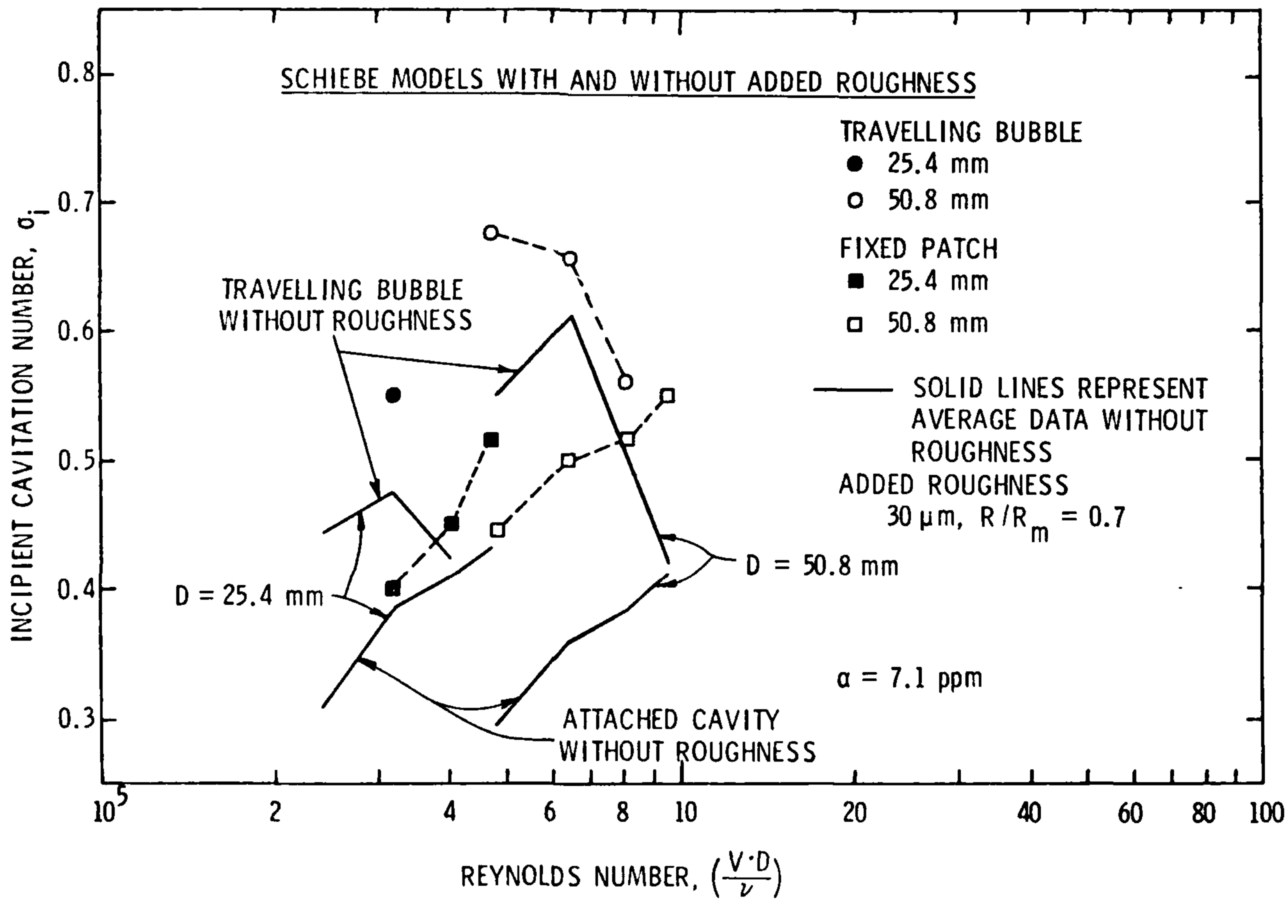


Figure 5. Cavitation Inception Data for the 25.4 mm and 5018 mm Models with and without Added Roughness

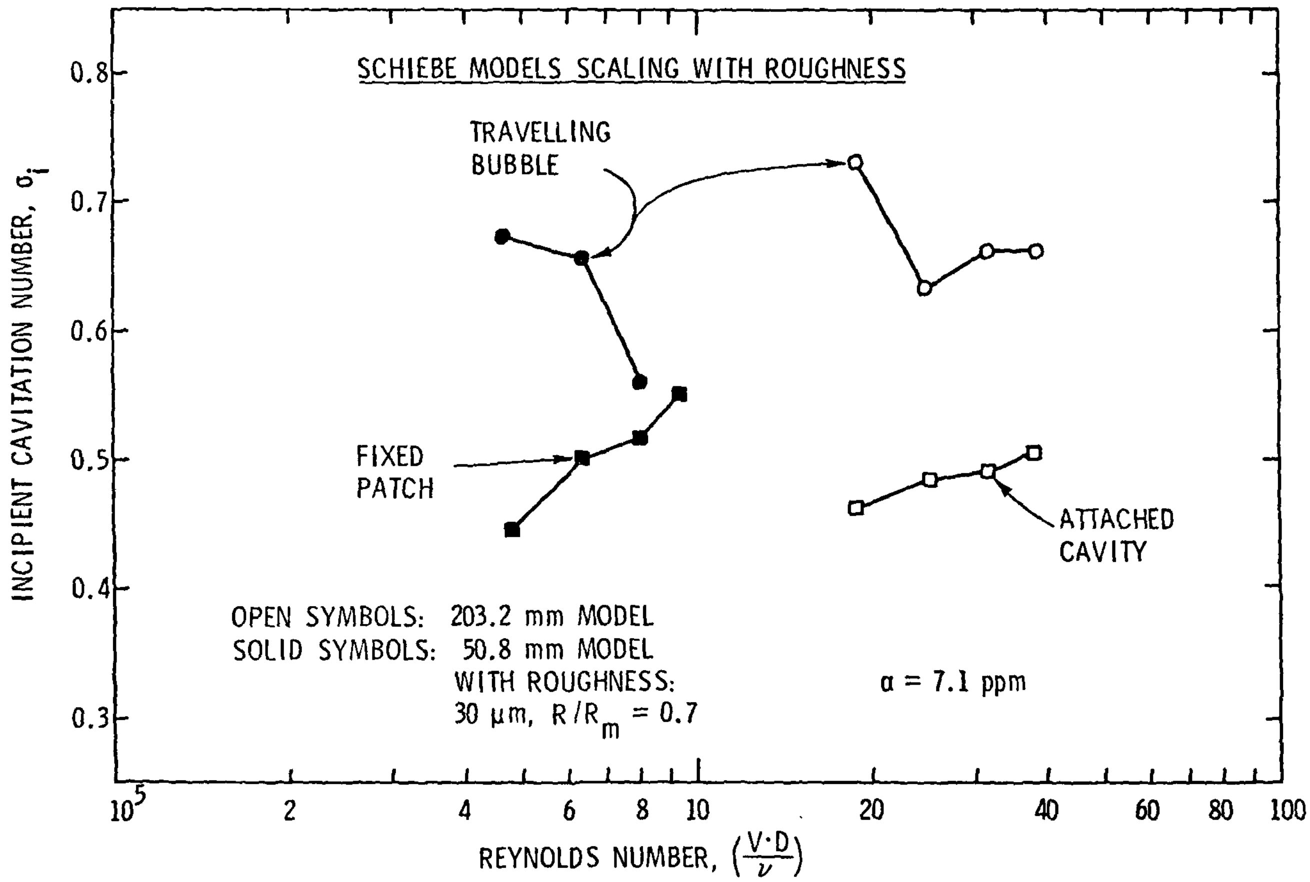


Figure 6. Comparison of Cavitation Inception Data for the 203.2 mm Model with the 50.8 mm Model with Added Roughness

DISTRIBUTION LIST FOR ARL UNCLASSIFIED TM 80-177 by M. L. Billet and J. W. Holl, dated 21 August 1980.

Commander
Naval Sea Systems Command
Department of the Navy
Washington, DC 20362
Attn: Library
Code NSEA 09G32
(Copy Nos. 1 and 2)

Naval Sea Systems Command
Attn: A. R. Paladino
Code NSEA 05H1
(Copy No. 3)

Naval Sea Systems Command
Attn: T. E. Peirce
Code NSEA 63R3
(Copy No. 4)

Commanding Officer
Naval Underwater Systems Center
Newport, RI 02840
Attn: Library
Code 54
(Copy No. 5)

Commanding Officer
Naval Ocean Systems Center
San Diego, CA 92152
Attn: Library
(Copy No. 6)

Defense Technical Information Center
5010 Duke Street
Cameron Station
Alexandria, VA 22314
(Copy Nos. 7 through 18)

Commander
Naval Surface Weapons Center
White Oak
Silver Springs, MD 20910
Attn: Library
(Copy No. 19)

Commander
David W. Taylor Naval Ship R&D Center
Department of the Navy
Bethesda, MD 20084
Attn: Library
Code 522
(Copy No. 20)

David W. Taylor Naval Ship R&D Center
Attn: T. E. Brockett
Code 1544
(Copy No. 21)

David W. Taylor Naval Ship R&D Center
Attn: W. B. Morgan
Code 15
(Copy No. 22)

David W. Taylor Naval Ship R&D Center
Attn: J. H. McCarthy
Code 154
(Copy No. 23)

Applied Research Laboratory
The Pennsylvania State University
Post Office Box 30
State College, PA 16801
Attn: GTWT Files
(Copy No. 24)

Applied Research Laboratory
Attn: M. L. Billet
(Copy No. 25)

Applied Research Laboratory
Attn: J. W. Holl
(Copy Nos. 26 through 31)

Applied Research Laboratory
Attn: B. R. Parkin
(Copy No. 32)

Applied Research Laboratory
Attn: R. E. Henderson
(Copy No. 33)

Applied Research Laboratory
Attn: D. R. Stinebring
(Copy No. 34)

Applied Research Laboratory
Attn: R. S. Moyer
(Copy No. 35)

Applied Research Laboratory
Attn: C. B. Yungkurth
(Copy No. 36)

DISTRIBUTION LIST FOR ARL UNCLASSSIFIED TM 80-177 by M. L. Billet and J. W. Holl, dated 21 August 1980.

Applied Research Laboratory
Attn: D. E. Thompson
(Copy No. 37)

Applied Research Laboratory
Attn: A. L. Treaster
(Copy No. 38)

Applied Research Laboratory
Attn: G. C. Lauchle
(Copy No. 39)

Applied Research Laboratory
Attn: E. G. Taschuk
(Copy No. 40)

California Institute of Technology
Division of Engineering for
Applied Sciences
Pasadena, CA 91109
Attn: A. J. Acosta
(Copy No. 41)

Netherlands Ship Model Basin
Haagsteeg 2
P.O. Box 28
67 AA Wageningen
The Netherlands
Attn: J. van der Meulen
(Copy No. 42)

Netherlands Ship Model Basin
Attn: G. Kuiper
(Copy No. 43)

Netherlands Ship Model Basin
Attn: J. van der Kooij
(Copy No. 44)

DAT

FILM